Capillary Plasma Radiation Source in the Soft X-Ray Region

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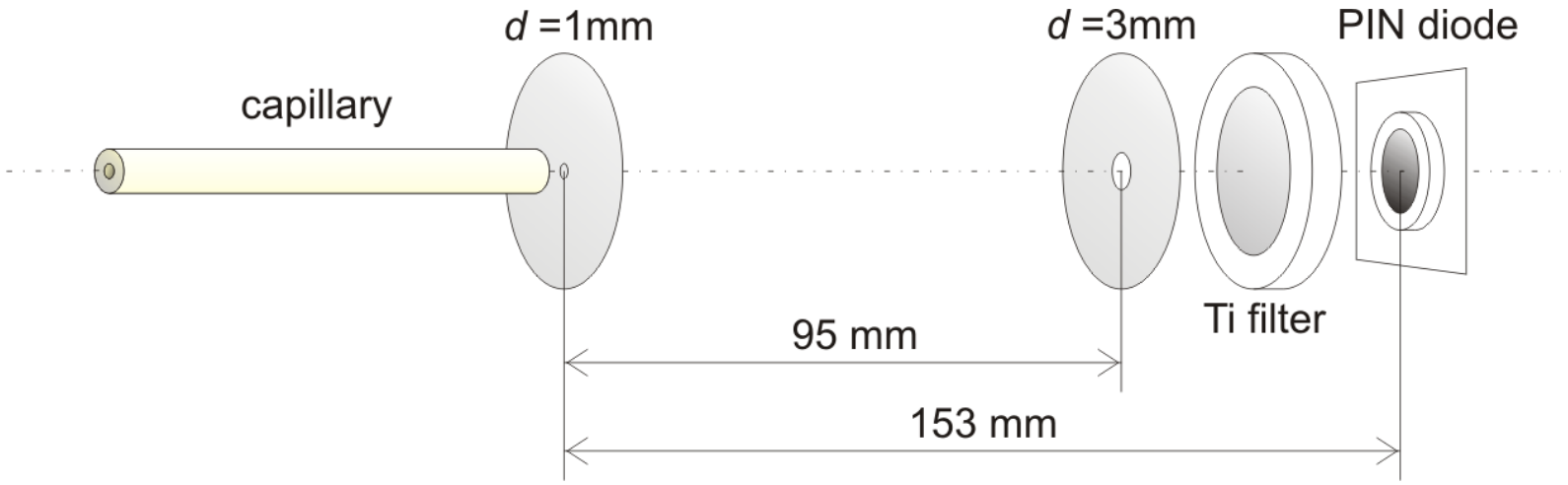
Outline

- Modeling of nitrogen capillary plasma by Z*- code
- Comparison of measured and evaluated
  - Current profiles
  - Radiation output power profiles in ww region
- Spatial and time dependences of plasma quantities
- Ray- tracing results
- Spectra estimated by FLYCHK - code

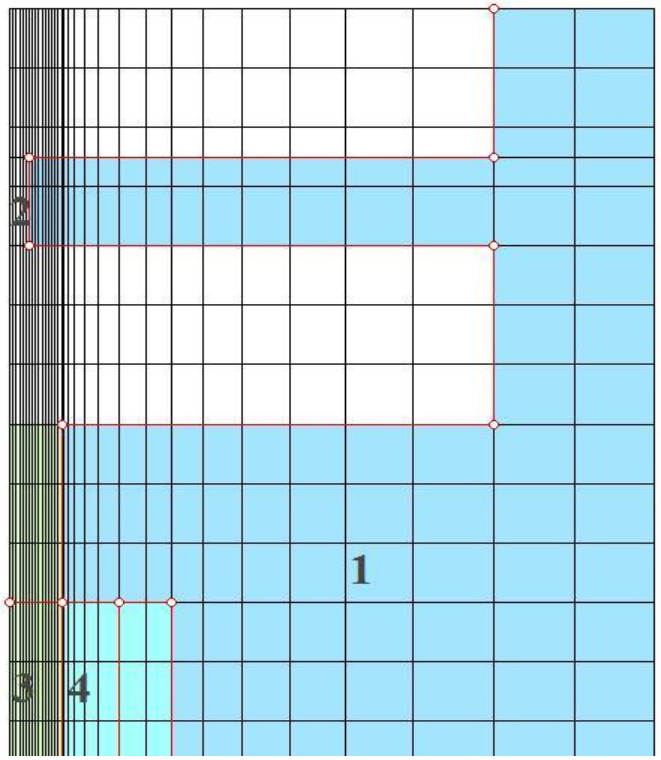
Investigated device



Capillary radius R_0 = 0.16 cm,
Capillary length L = 10 cm,
Nitrogen filling pressure 40 – 300 Pa,
Capacitor C = 21 nF, charged to U_0 = 70 kV.

See poster S24

Z* - code modeling



Anode part of the grid
1 – blue - outer electrode,
2 – outer orifice,
3 – yellow – inner part of capillary,
4 – green - capillary wall (dielectric)

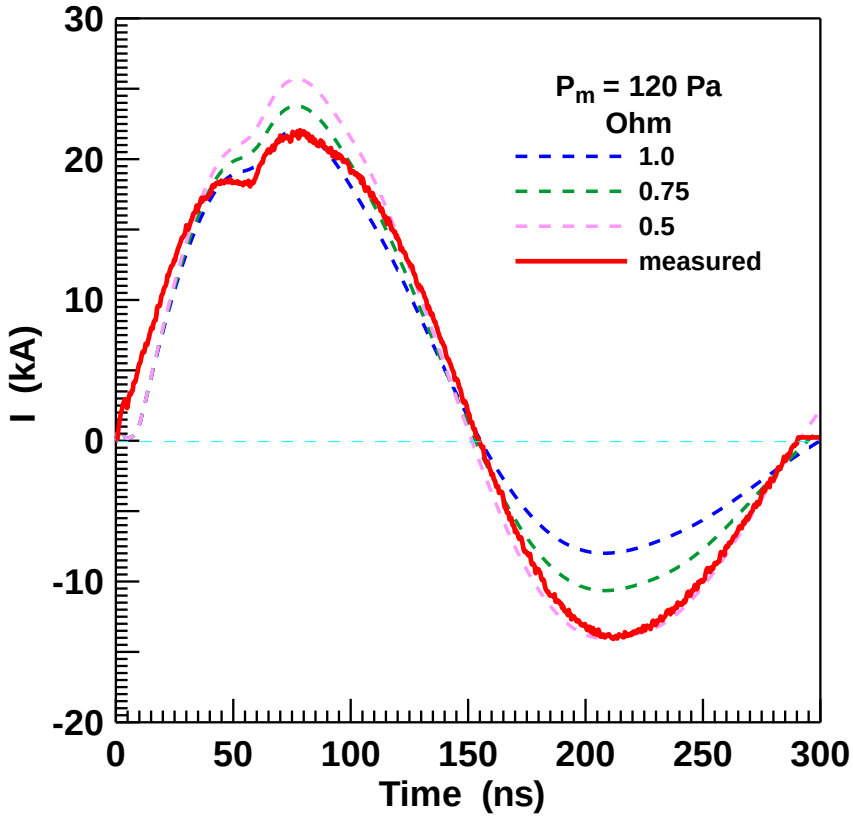
Rectangular unequal differential grid in cylindrical geometry according to the experimental set up

Capillary radius R_0 = 0.16 cm,
Capillary length L = 10 cm,

Nitrogen filling pressure 40 – 300 Pa,

Capacitor C = 21 nF,
Inductance l = 50 nH
Resistivity R = 0.7 Ohm
charged to U_0 = 70 kV.

Measured and evaluated current profiles



Charging voltage U_0 = 70 kV (used)

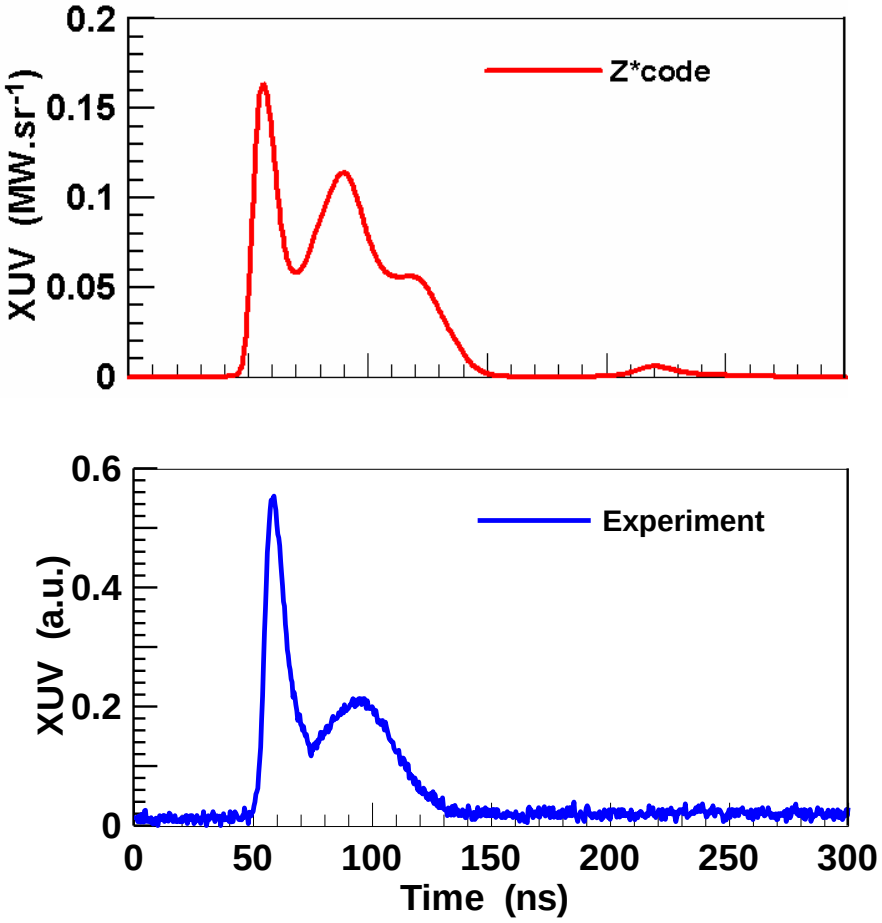
Capacitor C = 21 nF (used)

Parasitic inductance l = 50 nH (estimated)

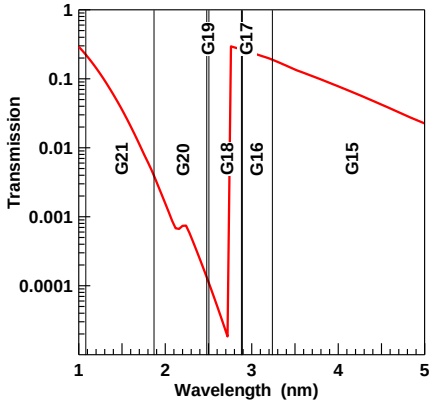
Parasitic resistivity R = 0.75 Ohm (fitted)

Evaluated and measured output power profiles

pressure P = 100 Pa, voltage U_0 = 70 kV



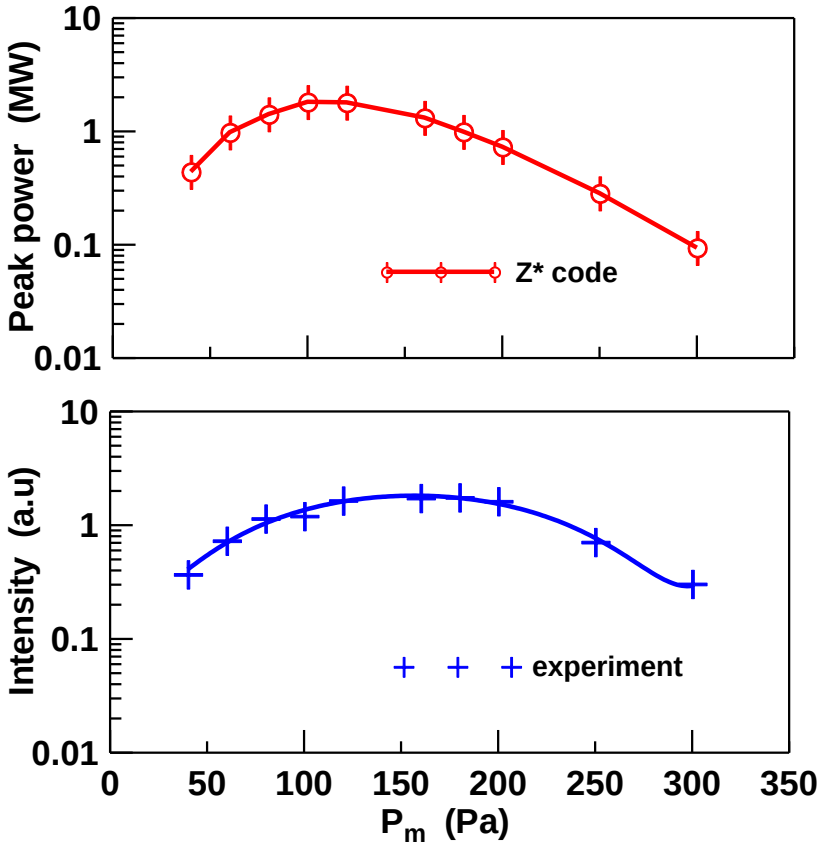
Evaluated output power in the spectral range 2.8766 – 2.8867 nm



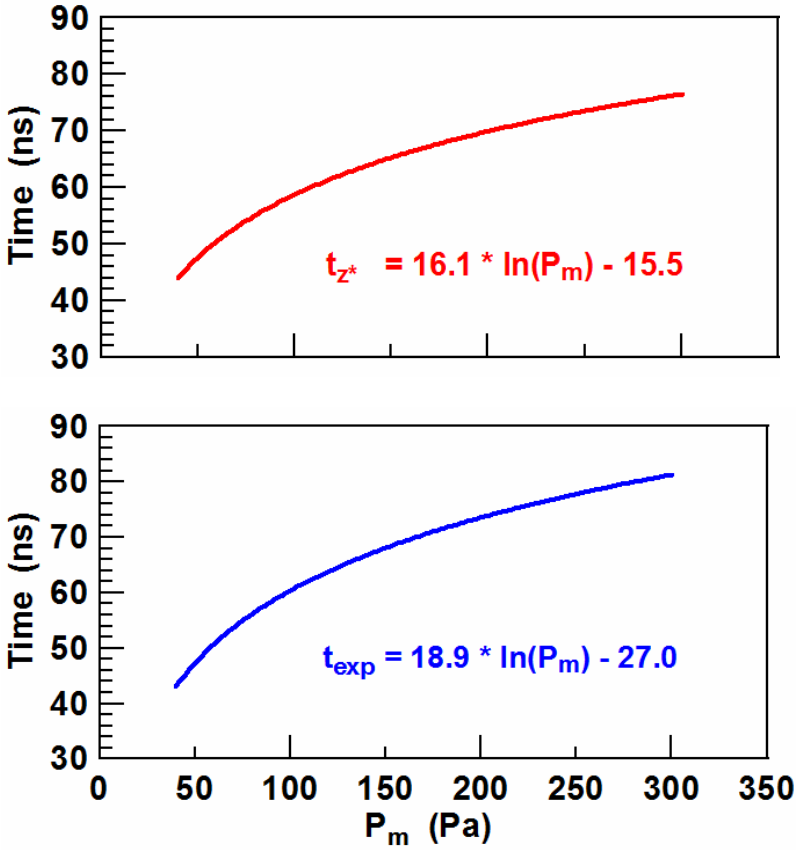
Measured output power passing through Titanium foil

Pressure dependences evaluated and measured

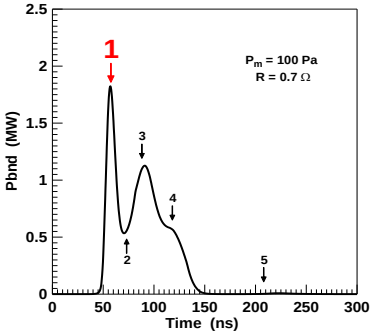
Peak values of emitted power

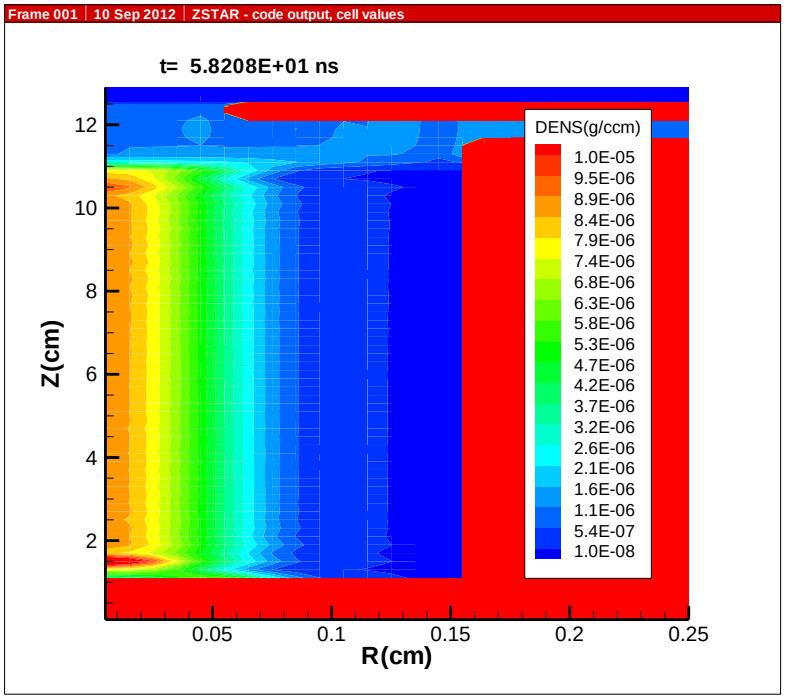


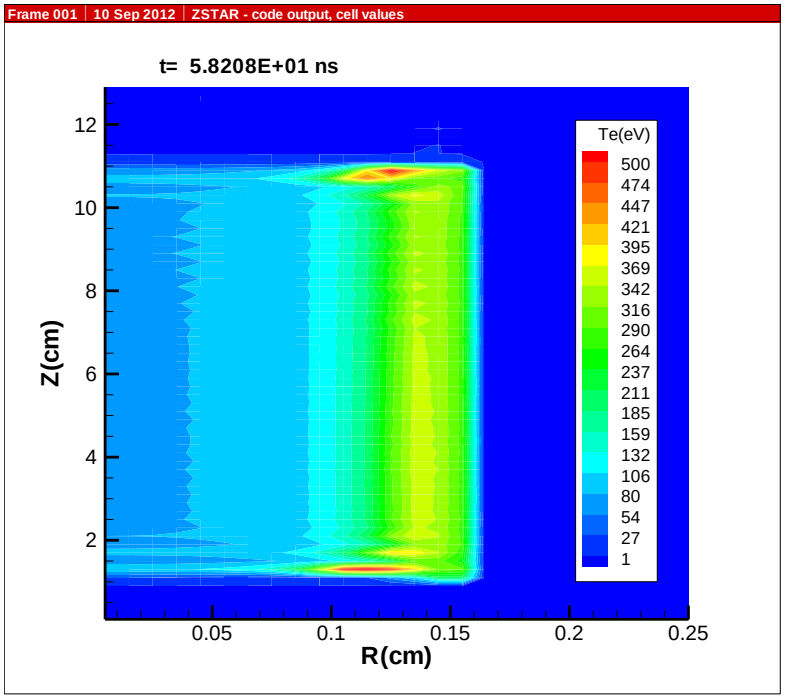
Time delays



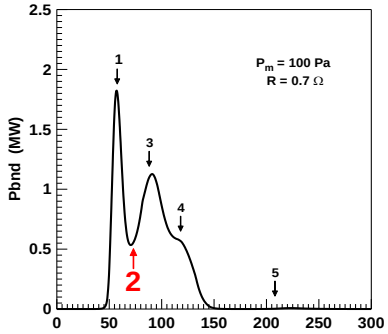
Plasma density and temperature at t = 58 ns

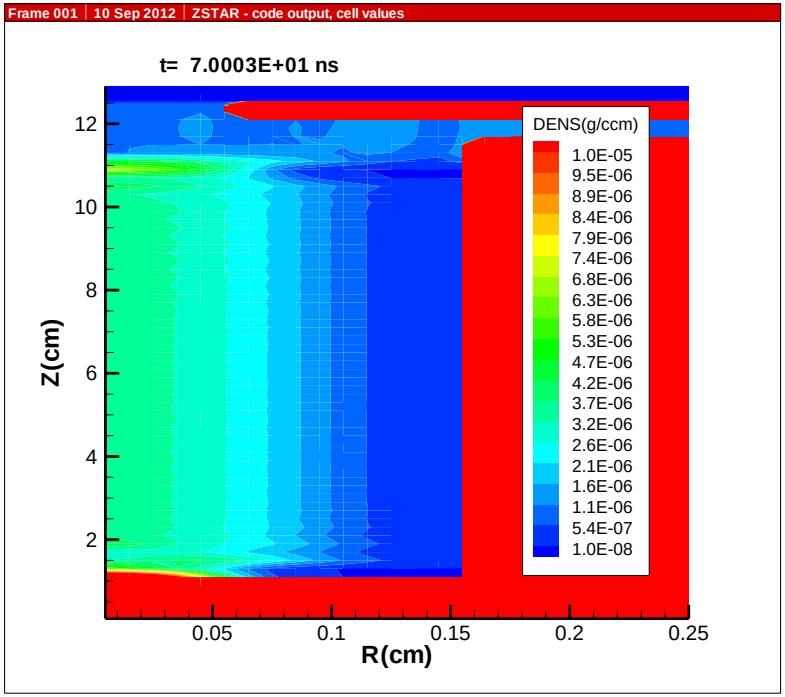


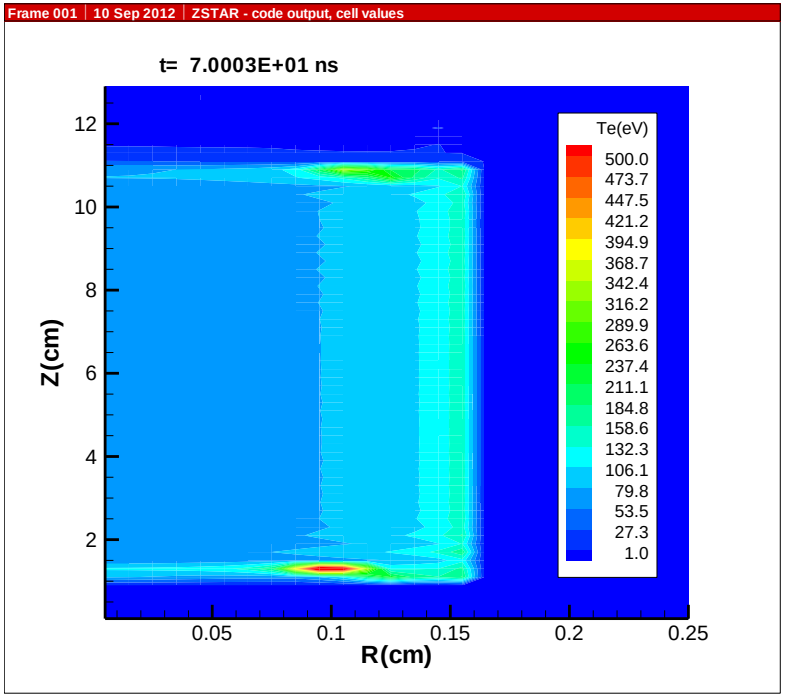




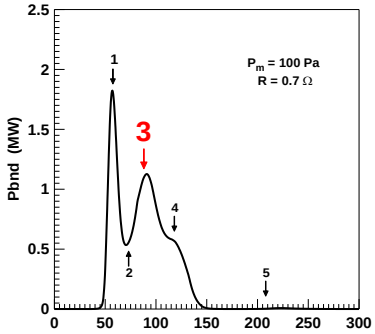
Plasma density and temperature at t = 70 ns

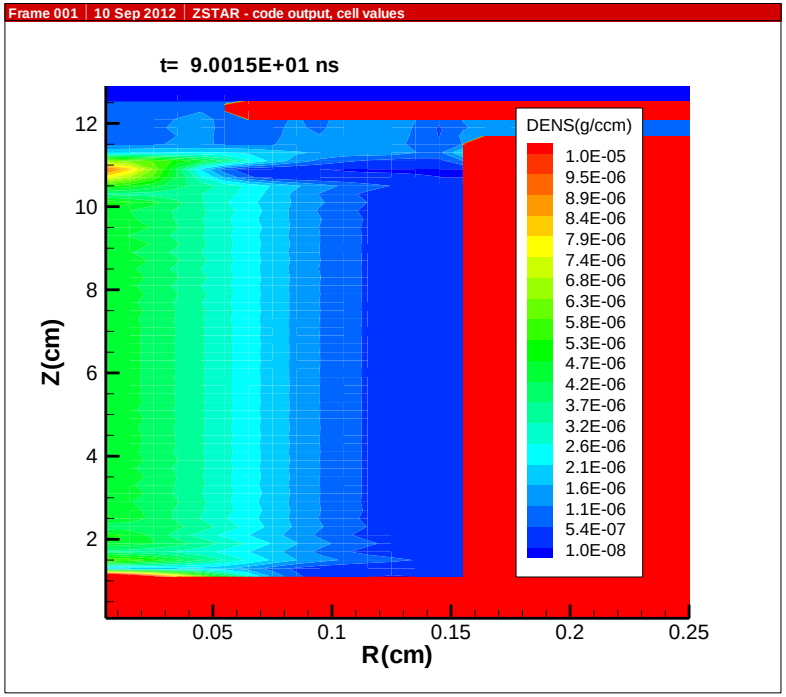


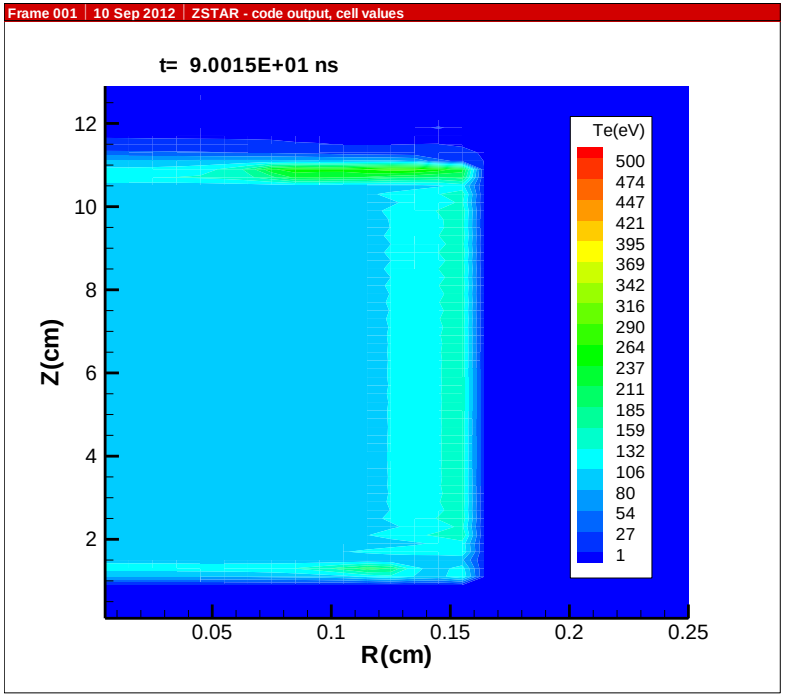




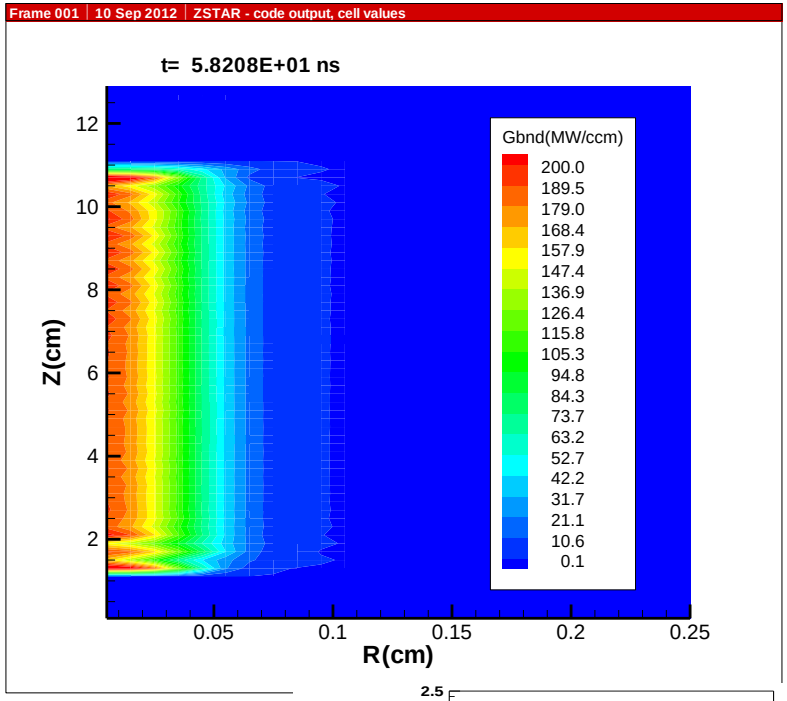
Plasma density and temperature at t = 90 ns

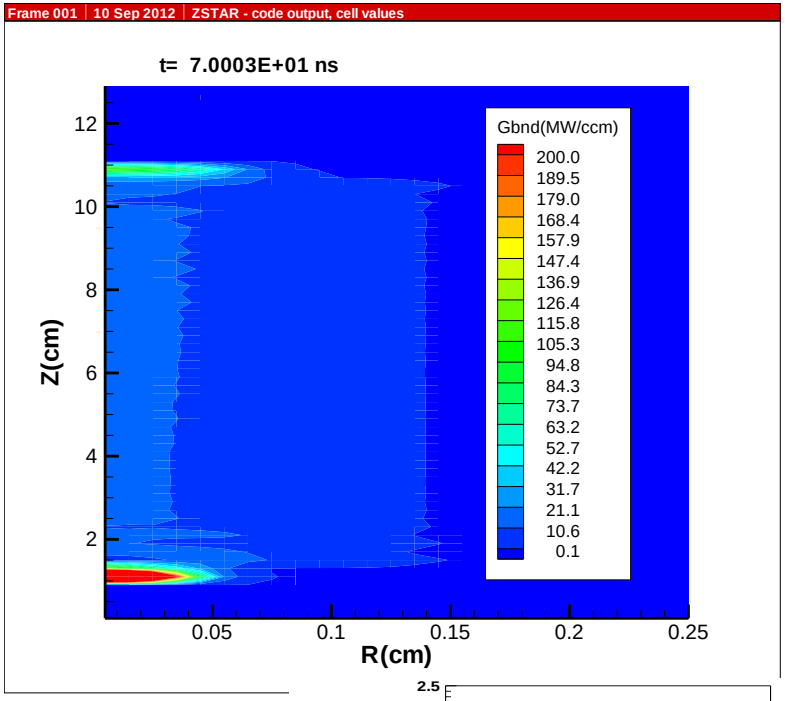


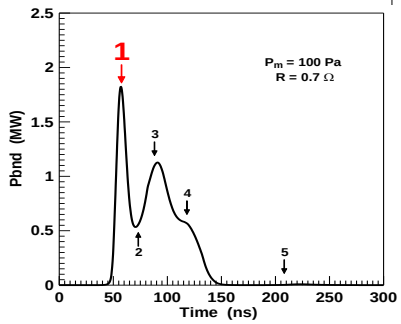


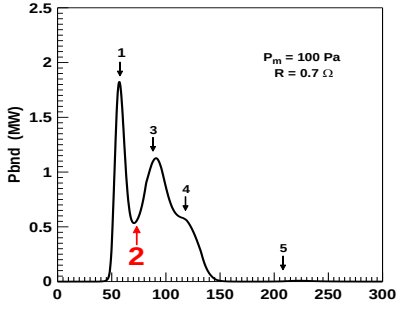


Power density emitted in the 2.8766 – 2.8867 nm **spectral band at 58 and 70 ns**

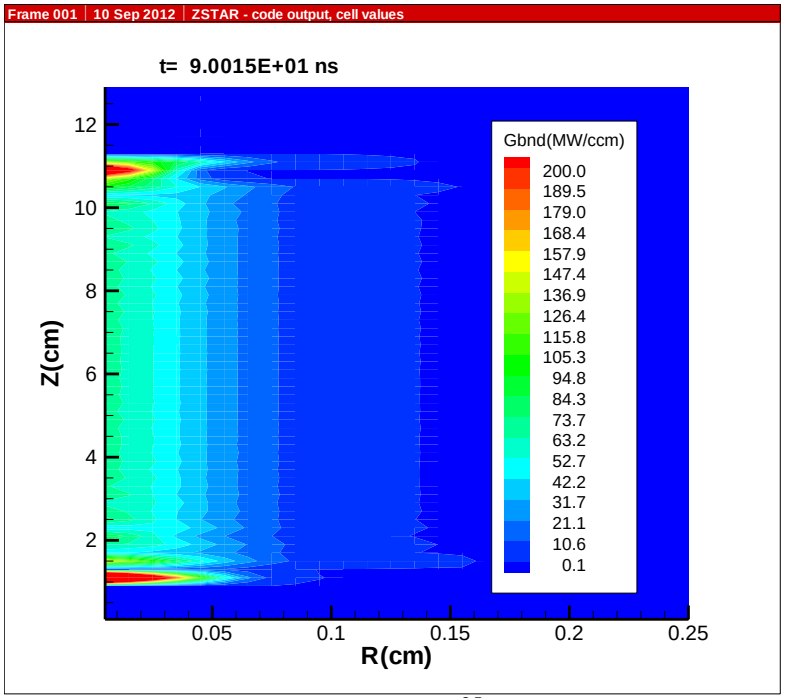


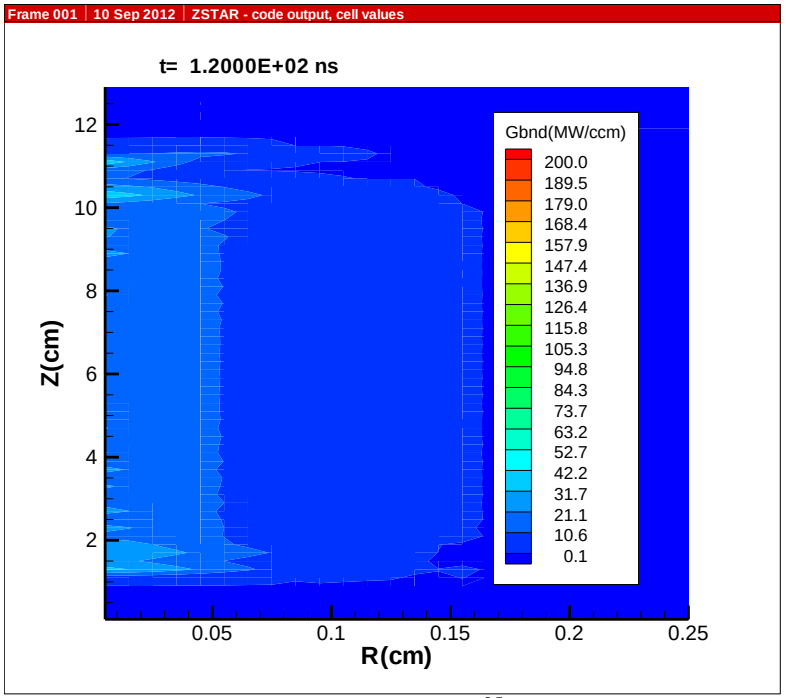


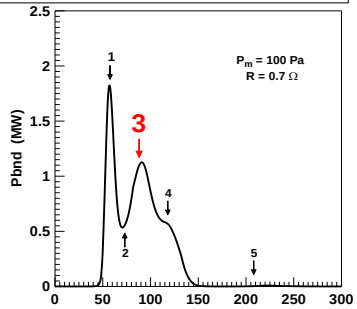


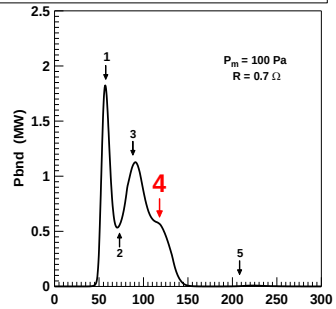


Power density emitted in the 2.8766 – 2.8867 nm **spectral band at 90 and 120 ns**





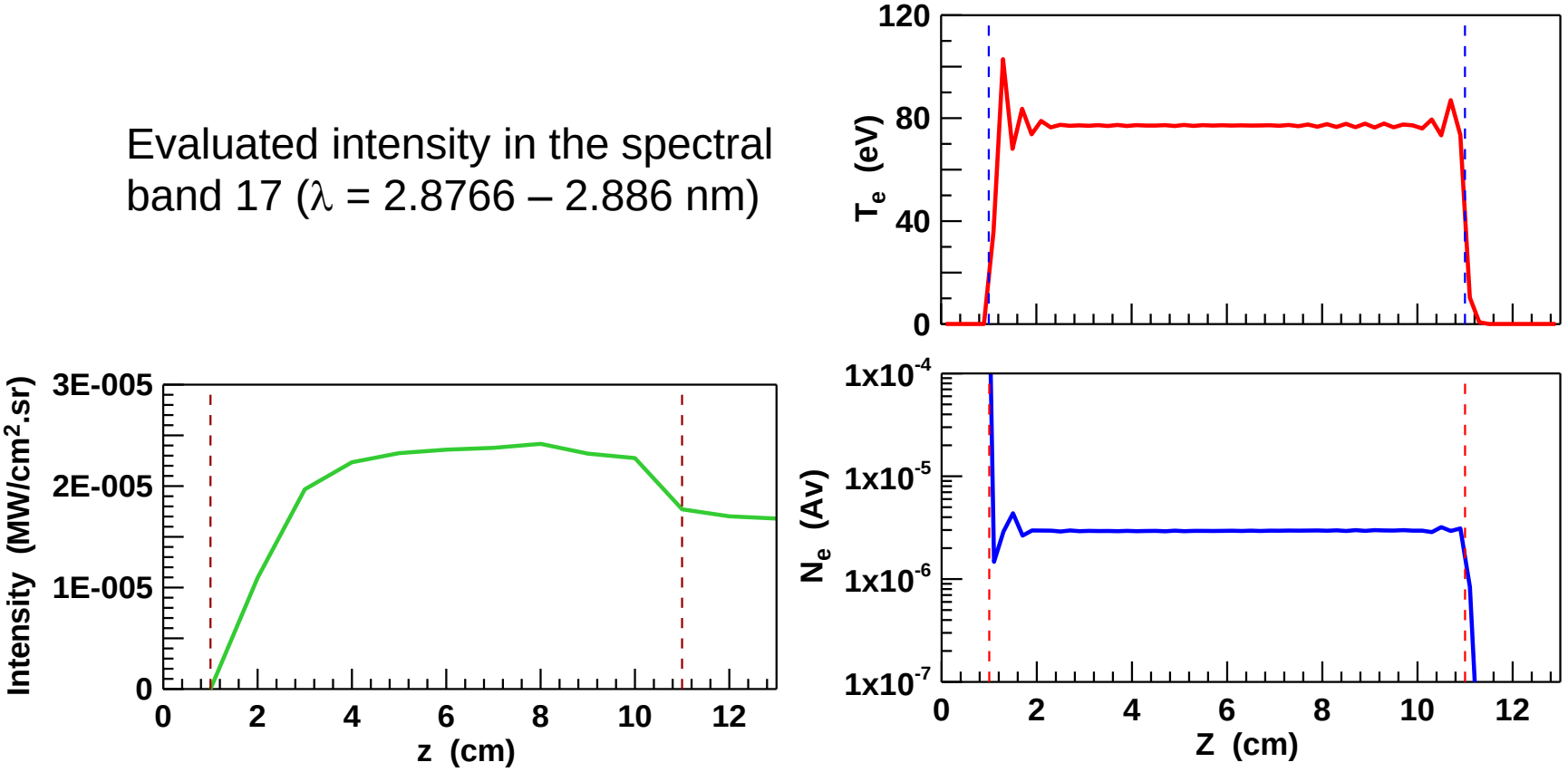




Ray tracing along capillary axis

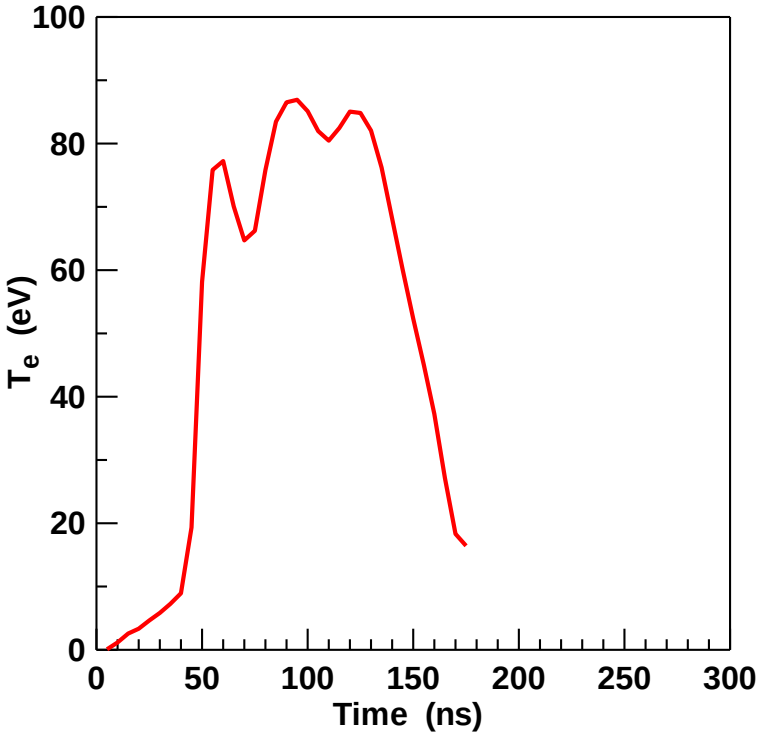
pressure P = 100 Pa, voltage U_0 = 70 kV, time t = 60 ns

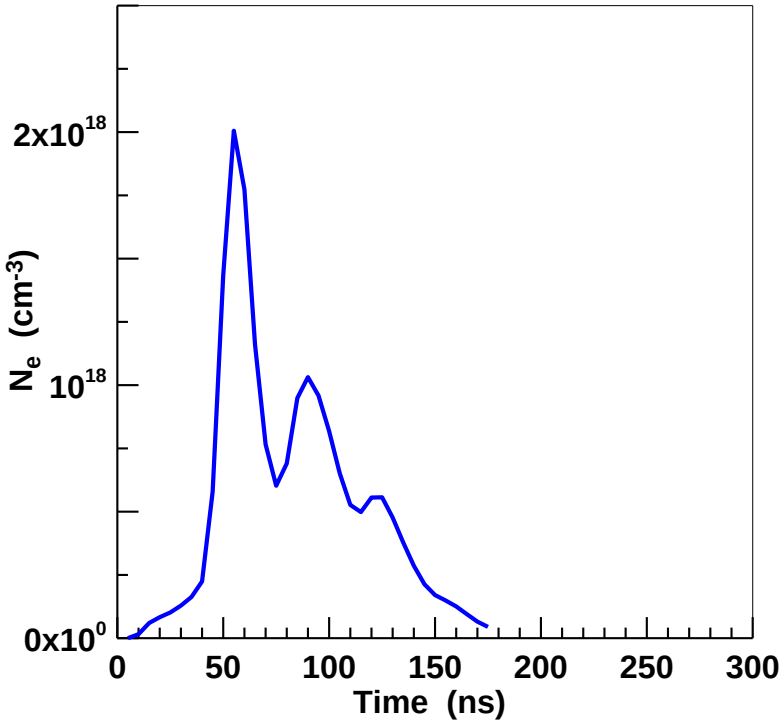
Evaluated intensity in the spectral band 17 (λ = 2.8766 – 2.886 nm)



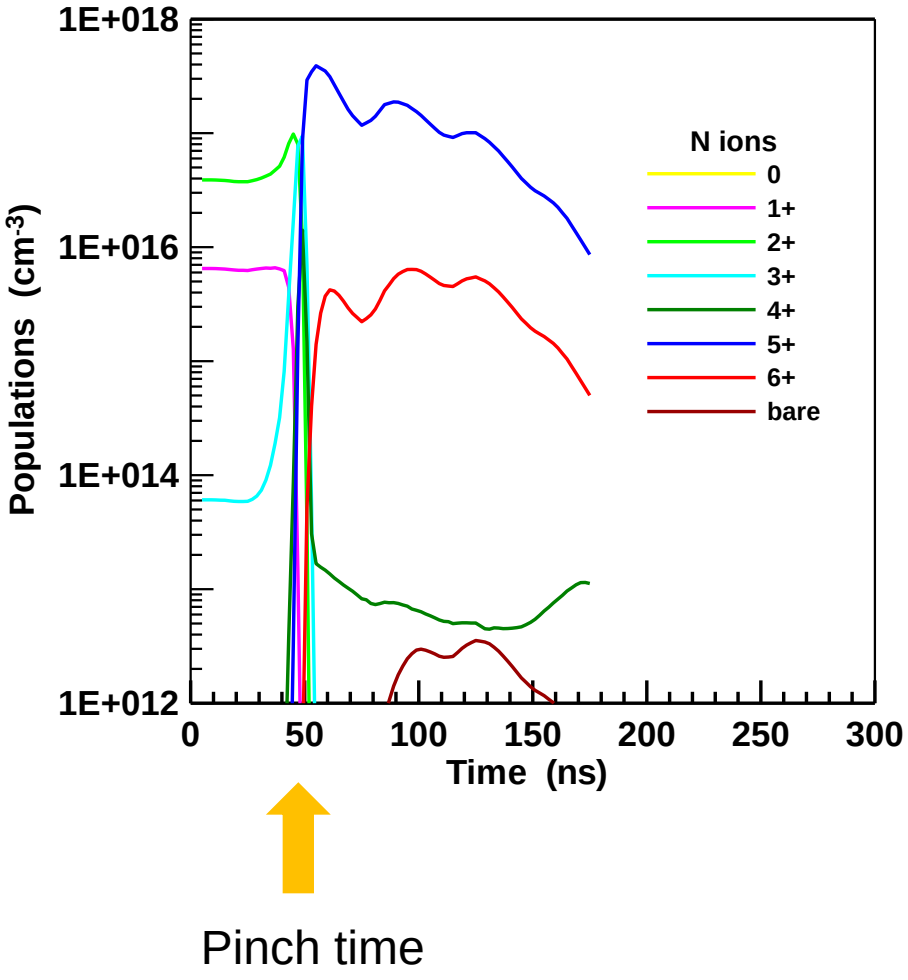
Time dependences of electron temperature and density in capillary center (r = 0 cm, z = 6 cm)

Pressure 100 Pa





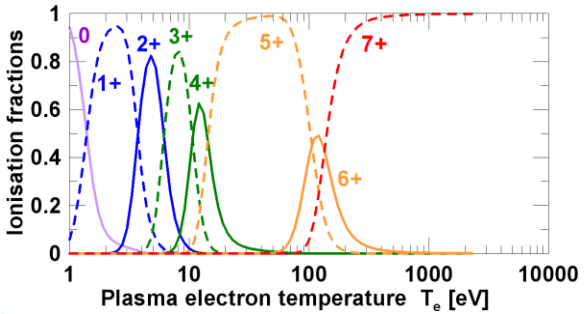
Ion kinetics evaluated according to FLY code



Time dependences of Te and Ne in capillary center used as input data

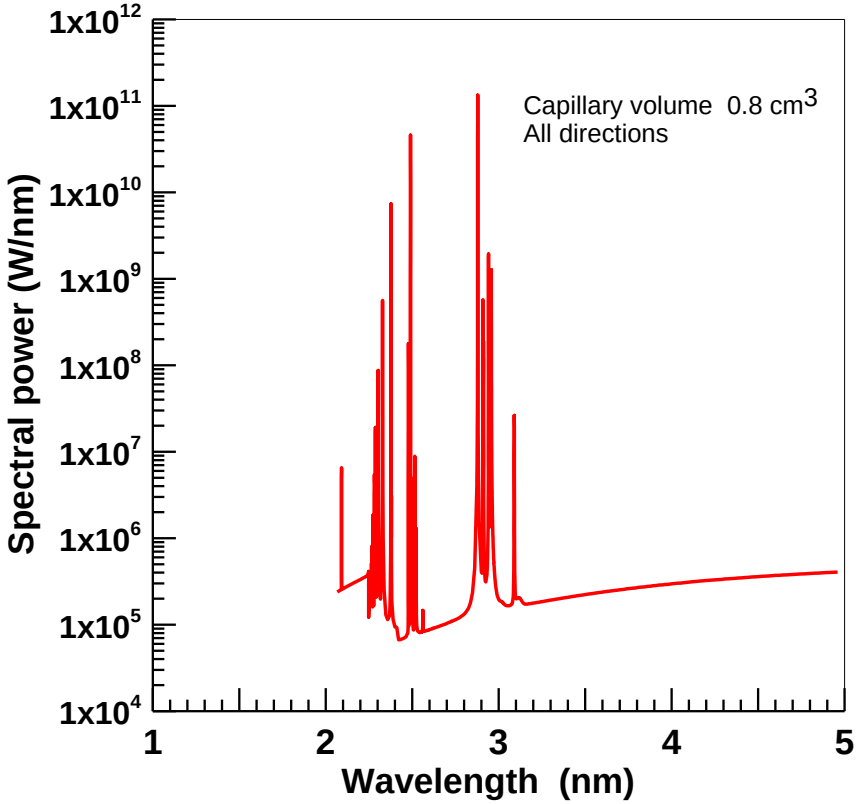
Quick change of ionization state at pinch time

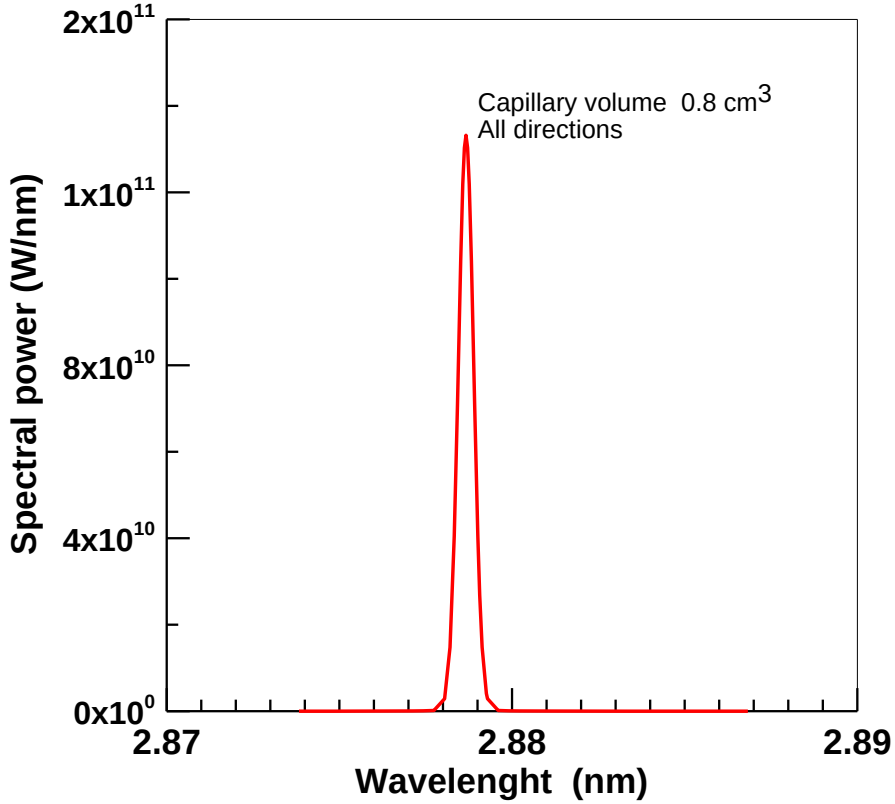
Prevailing He-like ions after the pinch



Instantaneous spectra at t = 56 ns

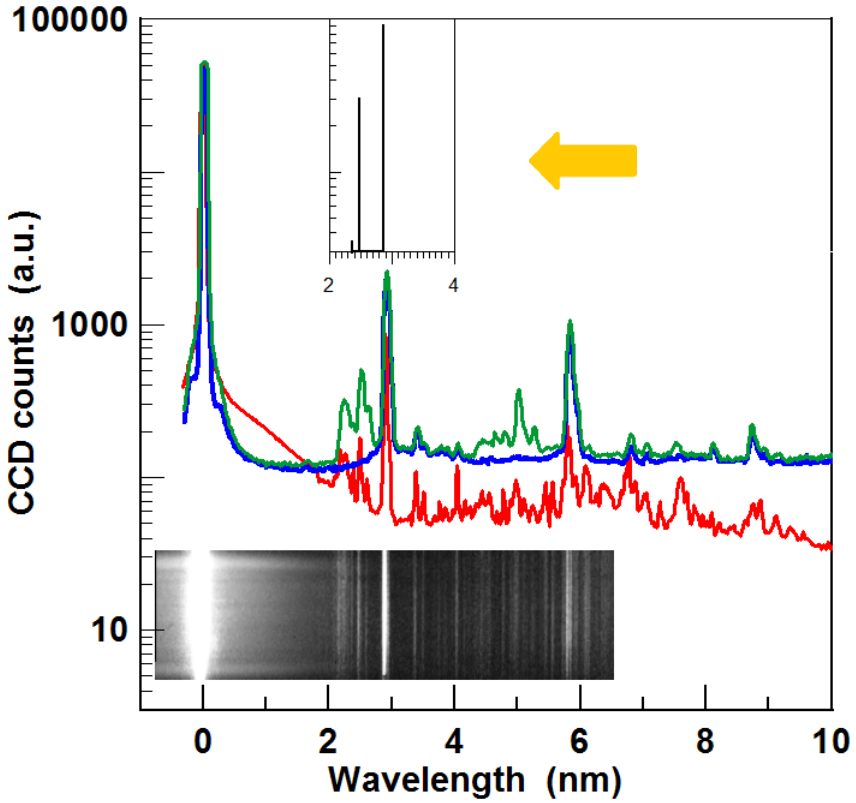
evaluated according to FLYCHK code





See poster S23

Spectra measured and evaluated



Diffraction patterns as registered by CCD camera

200 μm aperture without filter

400 μm aperture and Cr filter

400 μm aperture and Ti filter

Evaluated spectral lines of helium-like nitrogen (small embedded graph).

See poster S38

Conclusions

- **Both, calculated and measured current profiles were near to dumped sinus with the peak value ~23 kA and the half period ~150 ns.**
- **Output power at λ = 2,88 nm dominates other spectral lines emitted in ww spectral range**
- **Time dependences of the power in the line have pulse profiles with two remarkable peaks in the wide range of pressures.**
- **The highest peak value ~1.8 MW at pressure ~100 Pa was evaluated.**
- **The estimated energy 5.5 mJ.sr^{-1} (~10^{14} photons.sr^{-1}) corresponds properly to observed experimental value**
- **Pinching nitrogen capillary discharge as a source of monochromatic radiation in water window region is promising source for biological object imaging.**

Acknowledgement

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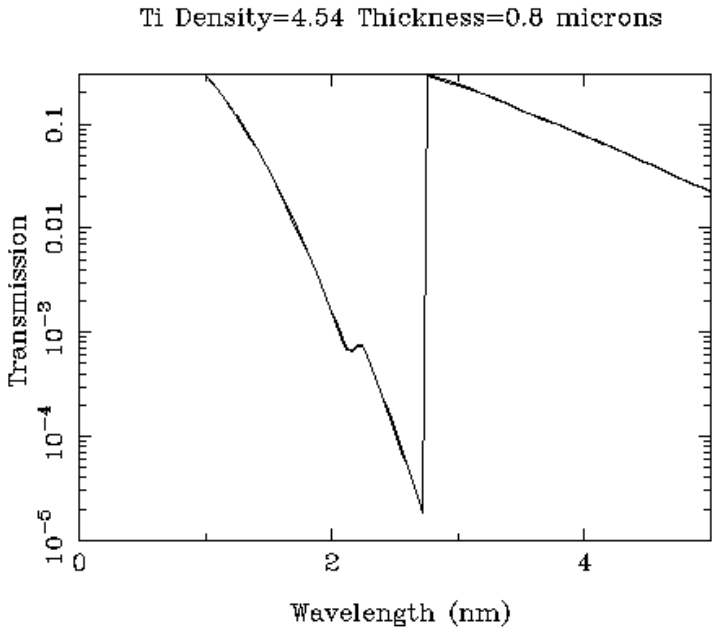
- GACR P102/12/2043 „Pulse Source of Soft X- Rays for Biomedical Applications“
- MEYSF CR Project LA 08024 „Research in the Frame of Dense and Magnetized Plasma Center“
- MEYS ESF Project CZ.1.07/2.3.00/20.0092 „Research Team Advancement at FBME CTU in Prague“

Thank you very much for your attention

Wavelengths of band boundaries and wavelengths of line emission inside the bands

Group	Lower limit λ_1 [nm]	Upper limit λ_2[nm]	Group width $\Delta\lambda$ [nm]	NVI spectr. line λ [nm]	NVII spectr. line λ [nm]	Filter edge λ [nm]
15	3.2340976	4.999888	1.7658			
16	2.8867111	3.2340976	0.3473			
17	2.8766645	2.8867111	0.0100	2.87870		
18	2.4996823	2.8766645	0.3770			2.72-2.76
19	2.4747353	2.4996823	0.0249	2.48980	2.47846	
20	1.865158	2.4747353	0.6096			
21	1.0763119	1.865158	0.7884			



	Wavelength (nm)		$g_k A_{ki}$	T Filter transmisivity	Relative intnsity observed
	2.0905		1.607 e+12		1.1 e +9 . n_{hy}
N VII	2.09106	1s-3p	0.803 e+12	0.7 e-3	0.5 e +9 . n_{hy}
	2.47792		6.020 e+12		0.6 e +9 . n_{hy}
N VII	2.47846	1s-2p	3.008 e+12	1.0 e-4	0.3 e +9 . n_{hy}
N VI	2.48980	$1s^2$-1s3p	1.547 e+12	1.0 e-4	1,5 e +8 . n_{he}
N VI	2.87870	$1s^2$-1s2p	5.427 e+12	0,26	1.4 e+12 .n_{he}